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Machining of Lightweight Frame Structures

S. Hannich[1]*, T. Brüggemann[1], M. Tiffe[1], D. Biermann[1], A. Zabel[1]

[1] Institute of Machining Technology, TU Dortmund University, Germany

* Corresponding author. Tel.: +49 (0) 231 755 5822; fax: +49 (0) 231 755 5141; *E-mail address*: hannich@isf.de.

Abstract

In the first part of the presented work the results of research regarding integration of acoustic emission sensor technology during the machining of material compounds will be depicted. Extruded aluminium alloys (AW6060) provide as a matrix material, while functional elements in form of conductive paths and reinforcing elements (1.4310) are embedded. The aim of this research is to detect material transitions precisely and to generate an automatable process controlling. To analyse the acoustic emission signals a real-time capable system is used. The frequency spectrum as well as the root mean square-value will be depicted for the experiments. The second part of the work outlines the development and testing of an automated modal impact hammer to provide an impulse based structural excitation source for experimental modal analysis. The use of this pendulum is to increase the repeatability, to enable the variability of the excitation force and to prevent so called double hits. Therefore it is well suited for frequency response measurements of tools. With these measured data, stability charts can be simulated in further steps. With this the milling tool can be used in the optimum range of parameters.

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Keywords: Aluminium; Machining; Acoustic Emission; Reinforcing Elements; Modal Testing; Impact Hammer.

1. Introduction

The application of thin-walled aluminium profiles generates several potentials for optimisation, for example in terms of weight saving. These profiles are used especially in the automotive industry because of their specific material characteristics, such as low density and corrosion resistance. In addition, aluminium alloys have a high formability [1,2]. But they also have some disadvantages compared to steel alloys. The strength of aluminium is partially low in contrast to most of the steel alloys, which leads to issues constructing security-relevant parts [3]. To improve the material specific characteristics, it is possible to reinforce the aluminium alloys with steel elements. Using reinforcing elements it is possible to increase the tensile strength, the tensile yield limit, the rigidity as well as the fatigue strength of the profiles. Because of the high formability of aluminium, the process of extrusion can be applied to produce composite profiles. Another possibility in this context is the embedding of functional elements, in particular, conductive paths.

To create joining points, the composite materials have to be machined. Using reinforcing or functional elements, the machining process gets more complicated. The different material characteristics lead to partially opposing requirements regarding the configuration of the tools or the process itself. In terms of the reinforcing steel elements, the high strength of these alloys cause high loads, which can result in greater wear or complete tool failures. In contrast to this, aluminium alloys can cause built-up edges and tend to generate adhesion processes, which can lock the chip flutes of the tool [2, 3]. When machining profiles with embedded conductive paths, it is important not to damage the functional elements. The machining process has to be stopped in the moment the tool penetrates the functional element, so that it is exposed and functional. Both applications require an exact detection of material transitions. One possibility to achieve this is the integration of an acoustic emission sensor technology. Acoustic emission depicts sound waves, that spread within a solid material for example because of a load. Figure 1 (a) shows the schematic set-up of an acoustic emission sensor.

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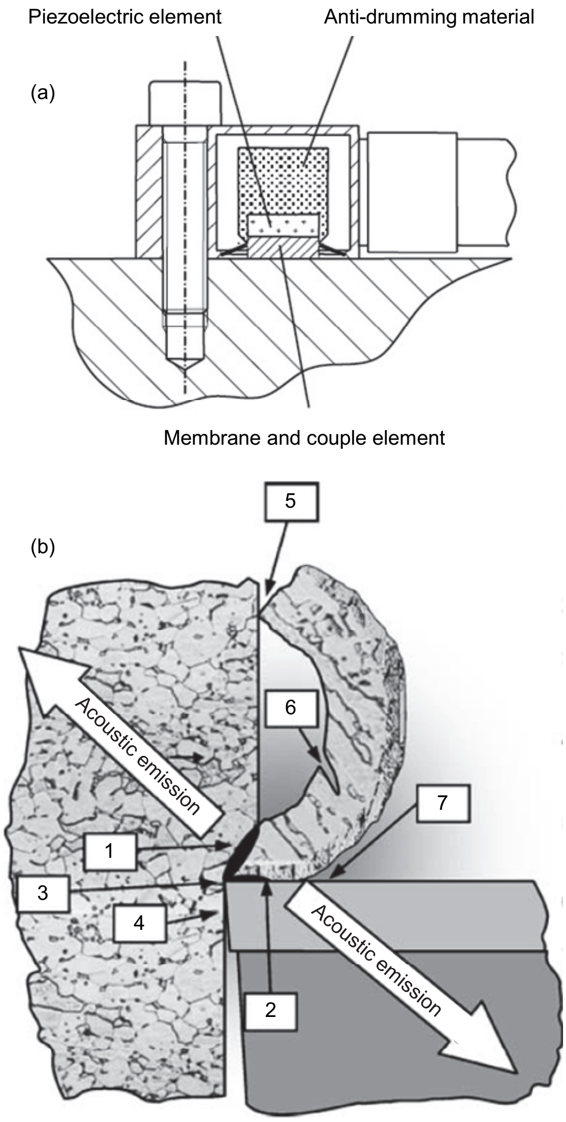

1: Plastic deformation
2: Friction (between chip and rake face)
3: Crack initiation and extension
4: Friction (between tool and workpiece)
5: Contact between chip and workpiece
6: Chip breaking
7: Friction (between chip and rake face)

Fig. 1. (a) Schematic set-up of an acoustic emission sensor [6] (b) Sources of acoustic emission [5]

The reason for using acoustic emission technology is that the position of the embedded elements is a subject to process-related fluctuations [4] and therefore it is recommended to have a flexible detection system. Figure 1 (b) shows possible sources of acoustic emission signals during machining processes. The main part of the acoustic emission signal is generated within the chip breaking. The other sources are less important [5].

In the present work the frequency spectrum as well as the root mean square-value will be depicted for the experiments. In a first step, the system response of machining the matrix material will be defined as a reference. Afterwards the variation of the signal, while machining the conductive paths as well as the reinforcing elements, will be measured. On the basis of these measurements suitable parameters will be generated in terms of a reliable and automatable process. Another aspect to be analysed, is the positioning of the acoustic emission sensor. It can be fixed via a magnet or a threaded joint. As a conclusion of this part of the study parameters and other process conditions will be advised to detect functional elements and reinforcing elements via an acoustic emission sensor technology.

The aim was to develop an automated modal hammer in order to characterise the dynamic behavior of tools and workpieces in milling machines.

In milling, machine tool vibration and workpiece wall vibration plays an important role concerning the workpiece surface quality and also the tool durability. The undesirable motions, which are often referred to as chatter, can result in wavy surfaces on the workpiece, inaccurate dimensions, and excessive tool wear. In order to decrease chatter and to machine the workpiece in the stable zone, a modal impact hammer can be used to detect the frequencies that are needed for the calculation of Stability charts.

The way of how to excite vibrations of the measured structure is given mostly by the aim of the modal test, precision requirements, and frequency range in which the modal parameters are to be determined. There are several ways how to excite vibration of a structure. They can be divided into two major groups:

1. Excitation using an attached exciter (shaker): The most common excitation sources is electromagnetic (often called electrodynamic) shaker.
2. Impact Excitation: The most common method of impact excitation is using an impact or modal hammer. [7]

1.1. Excitation Using Attached Shaker

Shaker testing is often used in more complex structures, and comprised many different excitation techniques. The excitation signals are generated by a signal generator and can be chosen from a variety of different possibilities, to match the requirements of the structure under test. Moreover, using a shaker, higher frequency ranges can be achieved. A modal impact hammer has an upper frequency range of around 8 kHz, while a piezoelectric shaker can offer frequencies as high as 80 kHz [7, 8, 9].

1.2. Impact Excitation Using Impact Hammer

The most common used method of transient excitation for modal testing is the impact hammer. Ideally the impact of a hammer acts as an impulse which excites all the frequencies in the frequency domain (impulse in time domain is constant value in frequency domain) [7]. In order to achieve an ideal impulse, the magnitude of the impulse has to be infinitely large and the duration of the impulse has to be infinitesimally small. However, this is not realistically possible and an approximation to this ideal impulse can only be achieved with a modal impact hammer. The aim of impact excitation is to have an input with a very short duration in order to achieve approximately constant excitation energy in the frequency range of interest.

2. Experimental setup

As stated above, an aluminium alloy (AW6060) provided as the matrix material for the experiments, while reinforcing elements made of steel (1.4310) and functional elements in form of conductive paths are embedded. Two types of workpieces have been used to conduct the experiments. In order to detect the reinforcing steel elements flat profiles with a wall thickness of t_W = 5 mm were used. The diameter of the reinforcing elements enlarges to d = 1 mm. The profiles with the embedded conductive paths were conducted as Z-profiles with a wall thickness of t_W = 8 mm. As an isolation the conductive paths were coated. Figure 2 shows the schematic cross section of the profiles.

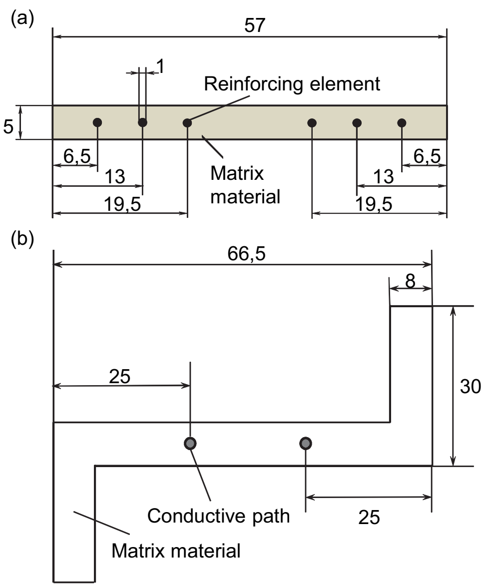

Fig. 2. Schematic cross section of the profiles

In order to analyse the acoustic emission signals, a real-time capable system (Optimizer 4D – Qass GmbH) was used. All experiments were conducted on a CNC machining centre of the type Grob BZ 40 CS. As far as this work is concerned, the process of circular milling with single-tooth tools was chosen. Different cutting speeds (v_c = 200…375 m/min), different feed rates (f = 0.05…0.2 mm), and various depths of cut (a_p = 0.25…1 mm) were analysed in case of changes of the acoustic emission signal. As far as this work is concerned, only representable combinations are described.

For the development of the automated modal impact hammer, firstly, one general purpose hammer was designed. Figure 3 shows the design of the general purpose automated impact hammer. This general purpose automated impact hammer can be used for wide range of modal testing of different workpieces or tool of different machine tools. As it can be seen from Figure 3, there are four main groups of elements: main body, driver cam, hammer and stopper in the design of the automated impact hammer.

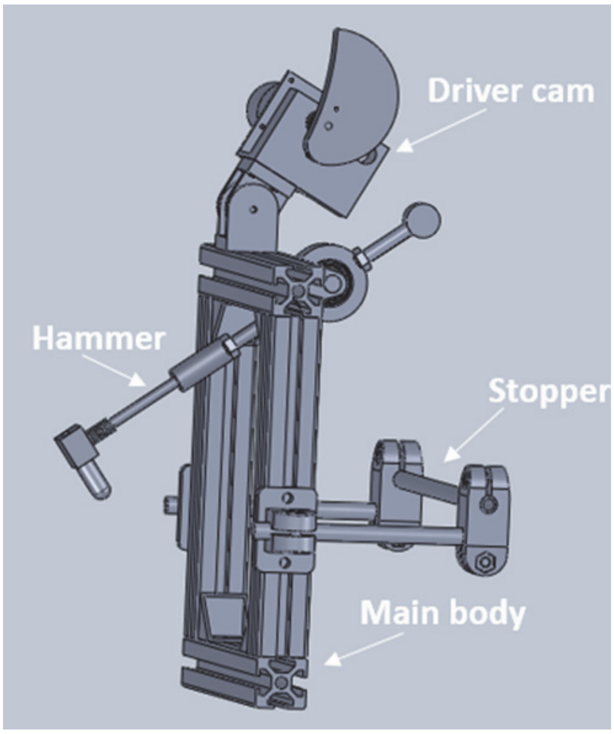

Fig. 3. Design of the general purpose of the automated impact hammer

The magnitude of the impact is basically determined by the mass of the hammer head and its velocity when hitting the structure. This is due to the concept of linear momentum, which is defined as mass time's velocity.

The linear impulse is equal to the incremental change in the linear momentum.

Due to the defined shape of the cam and the follower, the hammer head will reach nearly the same height in every cycle, therefore the velocity of the impact will be the same for each hit. Mass of the hammer can change via changing the hammer head or mounting an extra mass to the hammer housing. Therefore, in the case of automated impact hammer, the magnitude of the impact will be same in every single hit. However, in the case of manual impact hammer, the operator controls the velocity so the magnitude of the impact will change from measurement to measurement.

Moreover, force adjustment can be made by changing the angle between the joints in driver cam group.

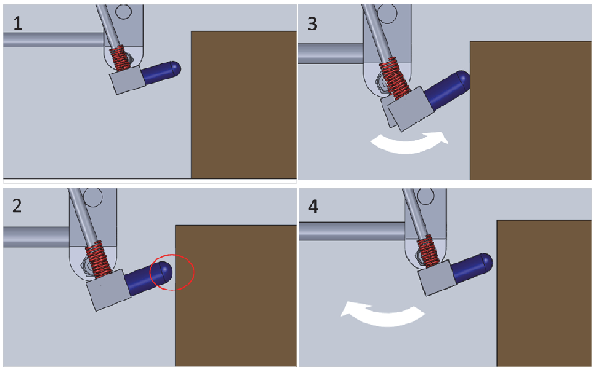

Fig. 4. Working principle of the stopper

A special attention must be given to the distance between the hammer tip and the target structure (point 2 in Figure 4) before the measurements. If the distance is too big, any input excitation cannot be obtained. If the distance is too short, it may cause double hits. In addition, the magnitude of the input force can be adjusted via changing this distance.

3. Results

In order to analyse the acoustic emission signals, the root mean square value was measured. This value can be displayed in the time range. Another calculated value was the frequency. Via a Fast Fourier Transformation (FFT) it is possible to convert the measured signals into the occurrent frequency spectrum. For an automatable detection of the reinforcing or functional elements, the Optimizer 4D is able to monitor a specific frequency range and then interact with the machine control to stop the process, when it detects energy values which are different from machining the matrix material.

At first, the influence of the distance between the acoustic emission sensor and the machining point was investigated. It was visible that the distance had no significant effect on the signal, because the dimensions of the profiles were small enough to generate stable process conditions. After that it was possible to analyse the root mean square value as well as the frequency while machining the composite materials. Figure 5 shows the measured data milling the aluminium with an embedded reinforcing element.

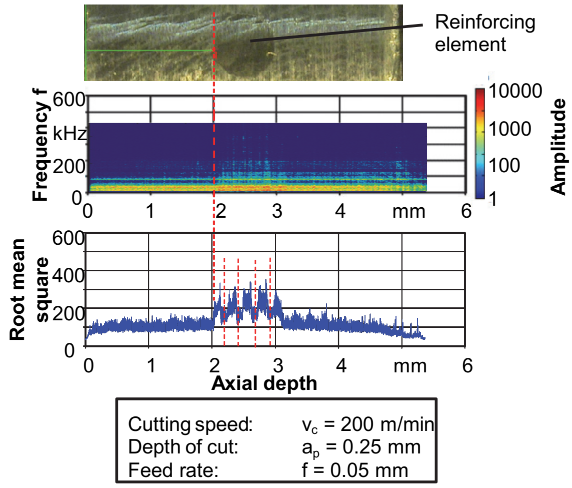

Fig. 5. Frequency and root mean square value machining aluminium with an embedded reinforcing element

For all experiments, single-tooth tools with a diameter of d = 5 mm were used. The bore diameter was enlarged to D = 7 mm. It is visible, that the root mean square value as well as the frequency grows every time the tool penetrates the reinforcing element. This effect is based on the higher strength of the steel elements compared to the aluminium matrix material. Because of the helical path caused by the process of circular milling, five peaks are noticeable.

A similar effect can be seen when machining profiles with embedded conductive paths. Figure 6 shows the frequency and the root mean square value conducting a representable experiment.

Similar to the machining of the aluminium with the reinforcing element, it is noticeable that the root mean square value as well as the frequency is stable when machining aluminium. At the point, the tool penetrates the isolation of the conductive path, a drop of the root mean square value can be detected. In the moment the machining of the conductive path starts, the root mean square value as well as the frequency increases.

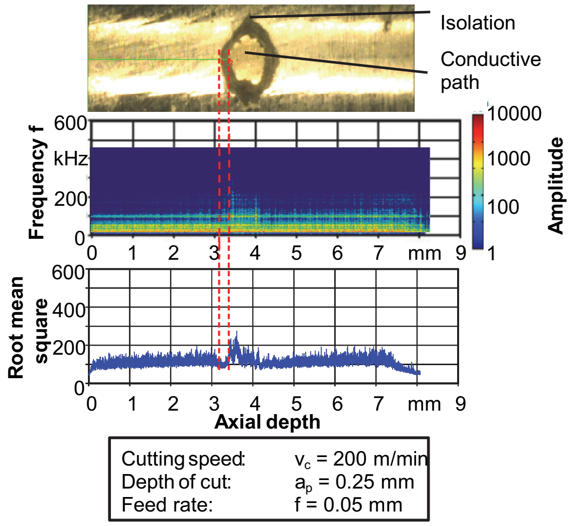

Fig. 6. Frequency and root mean square value machining aluminium with an embedded conductive path

Based on these investigations it was possible to detect reinforcing and functional elements and stop the machining before damaging the element. The aim was to find suitable machining parameters as well as energy levels to expose the elements against the matrix material. The energy levels were calculated on basis of the root mean square value. The acoustic emission sensor technology should trigger if a certain value has been reached. Therefore a single frequency range is analysed in real-time. Figure 7 shows some results of these experiments due to the detection of reinforcing and functional elements.

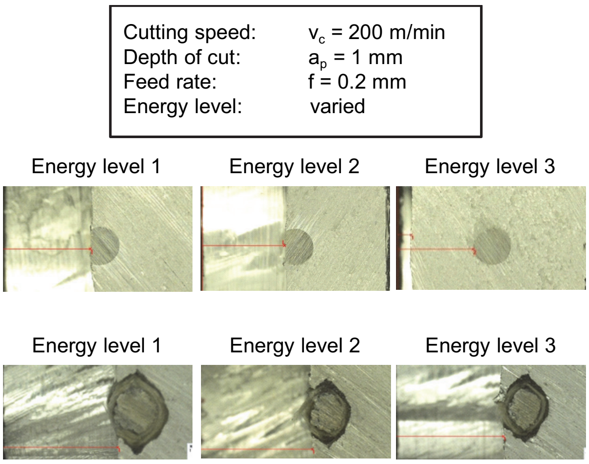

Fig. 7. Representable results of the detection and exposing of reinforcing and functional elements

The energy levels are sorted as following: Energy level 1 describes 70 % of the reference, energy level 2 stands for 50 % of the reference energy and energy level 3 depicts 30 % of the reference energy level. As it is noticeable, the sensor triggers too late if energy level 1 is adjusted. Parts of the reinforcing as well as the functional element are damaged. Energy level 2 generates good results in case of exposing the elements. At energy level 3 the sensor triggers too early. Just small parts or even nothing of the element is exposed. These results are representable for most experiments. Similar results could be seen using different cutting data. It was visible that the energy level had the largest influence on the result.

Conducting the presented experiments it was necessary to fix the sensor with a threaded joint. In further experiments two different possibilities to fix the sensor were investigated. At first the sensor was fixed by a magnet. This alternative was not operable because of damping effects. The machining of the reinforcing or functional elements generated no significant peaks in the required energy, so that a detection was impossible. Another efficient alternative to the direct mounting of the sensor was the use of an aluminium support plate. The detection was still possible and there was no need to fix the sensor at the workpiece.

The main objective for the development of the automated modal impact hammer was to eliminate double hits in the measurements. Figure 8 shows single hits obtained from the measurements.

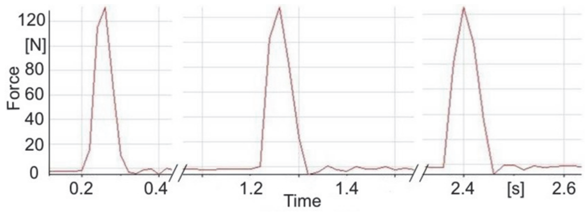

Fig. 8. Single hits obtained from the measurements with adequate distance

Another objective of the automated modal impact hammer was to have a repeatable process. Due to strong structure of the automated modal impact hammer and predefined pendulum motion of the hammer head, the location of the excitation point will be the same in every measurement. Figure 9 shows repeatability of the force magnitude obtained from four different measurements.

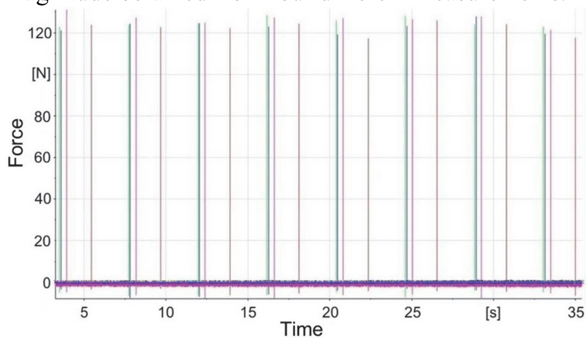

Fig. 9. Repeatability of the force

Force adjustment can be done by changing the dimension of the cam follower, changing the angle between the joints in driver cam group or changing the distance between the hammer head and the target structure. The important thing in force adjustment is to maintain the repeatability of the force during the force adjustment. Force adjustment and repeatability of the adjusted force gained from different measurements can be seen in Figure 10.

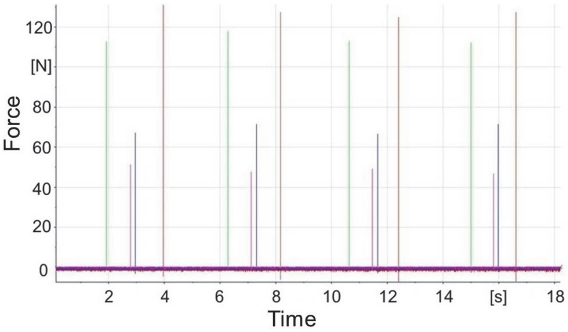

Fig. 10. Force adjustment and repeatability of the adjusted force

As it can be seen from the figure, different force magnitudes for different structures can be obtained. However, adjustment of the force is not easy and it requires some trial and errors to the perfect adjustment.

As is plainly evident from the results of the experiments, automated modal impact hammer: (i) increase repeatability of the process while reducing the time and manual effort; (ii) provide single hit in every trial, (iii) provide adjustable force (iv), provide an operator-independent process. Therefore, the data gained from the automated modal impact hammer for the simulation is more reliable than the data obtained from manual modal impact testing. In order to see the quality difference between manual modal impact hammer and automated modal impact hammer measurements, milling machine setup with unusual long tool is used. Ten hits were made on the structure with both hammers and PULSE Reflex Modal Analysis software is used. Firstly, measured input and output signals are used to obtain FFTs. Then, FFTs of the data were averaged, and finally, averaged data were used to compute required frequency response functions. Manual hammer measurements were made with a very experienced operator

4. Conclusion

The experiments have shown that it is possible to detect reinforcing and functional elements in an aluminium matrix by an acoustic emission sensor technology. Furthermore it was possible to expose the elements against the matrix material, but before it was necessary to get the reference energies. A sufficient amount of experiments dependent on the setup is essential to generate stable and working process conditions.

The results from preliminary testing of the automated modal impact hammer are proving that the device can provide a satisfactory alternative excitation methodology for the machined workpiece and the milling machine. All the objectives mentioned above are completely fulfilled by the device. However, it should be noted that the device was designed to impart relatively low impact energy and is therefore only suitable for application to small structures. The maximum force that can be performed by the device is limited. Therefore it cannot be used when the structures require larger force magnitude. Moreover, it has some disadvantages related to compactness of the design and it can only be used in vertical direction. A redesign of the device would be required for the use in vertical direction and to induce the energy levels appropriate for large- scale structural excitation.

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